

Ch. 6

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WATER RESOURCES DEVELOPMENT PROJECT
CHARLES RIVER DAM
CHARLES RIVER BASIN, MASSACHUSETTS
NAVIGATION LOCKS AND FACILITIES

PERTINENT DATA

Purpose Flood Control, navigation, and highway transporation.

Location

State	Massachusetts
County	Suffolk
City	Boston
River	On the Charles River 2,250 feet downstream of the present Charles River Dam.

Surface Area

Datum Relationship M.D.C. Base is 105.65 feet below mean sea level (M.S.L.), U.S.C. & G.S.
Datum of 1929 (105.65 M.D.C. = 0.00
M.S.L., U.S.C. & G.S. (1929))

Tides, Boston Harbor (Elevations, feet M.D.C. Base)

Highest tide of record, April 14, 1851	115.7 (116.6 adjusted to 1970)
Mean high water	110.2
Mean low water (M.L.W.)	100.8
Highest tide, modern record, Dec. 29, 1959	115.0

Upstream Pool

Normal Basin 108.0 feet, M.D.C. Base

Downstream Pool Tidal, elevation varies

Lock Features

<u>Feature</u>	<u>Large Lock</u>	<u>Small Locks</u>
Number of locks	One	Two
Purpose	Commercial shipping, supplement recreational	Recreational boating only
Length	300 feet	200 feet
Width	40 feet	25 feet

<u>Feature</u>	<u>Large Locks</u>	<u>Small Locks</u>
Lift	2.4 feet @ Mean Sea Level -2.2 feet @ Mean High Water 7.2 feet @ Mean Low Water	
Lock Gates Tide End	Sector 2 Sections ea. 31' x 24' rad.	Sector 4 sections ea. 23' x 13.5' rad.
Basin End	2 sections ea. 26' x 24' rad.	4 sections ea. 17' x 13.5' rad.
Water Depth Above Tide Sill	14.8 ft. @ mean low water	6.8 ft. @ mean low water
Basin Sill	17.0 ft. @ normal pool elevation	8.0 ft. @ normal pool elevation
Chamber Floor	16.8 ft. @ MLW	8.8 ft. @ MLW
Filling and Emptying Culverts	Two @ 6' x 7' each	Two @ 4' x 4' each
Discharge per Culvert	408 cfs @ 8 ft. head	190 cfs @ 8ft. head
Velocity in Culvert	9.7 fps @ 8ft. head	11.9 fps @ 8ft. head
Operation	6.0' x 7.0' Slide Gates	4.0' x 4.0' Slide Gates
Wall Ports	52 - 10" Ø per culvert	46 - 8" Ø per culvert
Recreational Boat Capacity	70 - 75 Boats per hr.	35 - 40 Boats per hr.

B. INTRODUCTION

1. GENERAL - The proposed Charles River Dam will be located in the city of Boston, approximately 0.7 mile upstream from the confluence of the Charles and Mystic Rivers at Boston Inner Harbor and 0.4 mile downstream from the existing Charles River Dam, see Plate 7-1. The plan proposed herein consists of three navigation locks to replace the single lock at the existing Charles River Dam. As shown on Plate 7-2, there will be two small boat locks each 200 feet by 25 feet wide, and one commercial lock measuring 300 feet by 40 feet. The depth of water over the large lock tide sill at mean low water is 14.8 feet, at mean sea level 19.6 feet, and at mean high tide the depth is 24.2 feet. At the basin sill the normal depth of water will be 17 feet. The clear width of the small locks, 22 feet, will enable two average sized pleasure craft to lock side-by-side with allowance for a floating mooring system along each wall. The length of the small locks was evaluated on the basis of capacity. When required by demand, all three navigation locks could be used for passing pleasure boats. The capacity of such an operation would be between 150 and 160 boats per hour in the demand direction. The average draft, for pleasure boats, is 2-1/2 feet and the maximum is 5 feet. At mean low water the depth of water over the tide sill will be 6.8 feet, 11.6 feet at mean sea level, and at mean high tide there will be a 16.2-foot depth of water at the sill. At the normal pool level the basin sill will have a depth of water of 8 feet. To effect the safe and expeditious passage of boats at peak demand, it is proposed to utilize electric traffic and audio controls at the lock entrances. These controls as well as lock filling, emptying and lock gate operations will be monitored from the Control Stations, as subsequently discussed.

C. HYDRAULIC DESIGN

2. LOCK FILLING AND EMPTYING SYSTEM

a. General. - Filling the lock chambers would be by circular wall ports along the length of each lock wall, as shown on Plates 7-3, 7-4 and 7-5. The ports stub from the base of continuous, rectangular sidewall culverts (see Plates 7-6 and 7-7) which are fed from three rectangular openings in the endwalls at each end of each lock. Flow through the culverts is controlled by slide gates. There is one slide gate at each end of the culvert located between the endwall intakes and chamber ports. Because of the variation in the tide elevation above and below the fixed level of the upstream pool, each component of the filling system must also function efficiently as part of the emptying system.

b. Lock Chamber Filling and Emptying. - Filling and emptying the lock chamber will be by means of gravity discharge through the lock wall culverts from the higher body of water.

c. Unwatering the locks for maintenance and inspection purposes is accomplished by pumping through a wetwell until the lock floor is drained. The wetwell sump elevation is low enough to empty, by gravity, both the small and the large lock chambers as well as the floor zone between the lock bulkhead and the sector gate sills. Unwatering of the pump station forebay and discharge chambers will also be accomplished through this unwatering system. Pumping operations for the navigation locks are described in Paragraph 4. Pumping operations for the pump station are discussed in Design Memorandum No. 5, "Pumping Station".

3. HYDRAULIC CALCULATIONS

a. General. - Sidewall culverts were sized after inspecting several geometric configurations and arrangements. Analysis of culvert characteristics was based on an 8-foot initial static head between the chamber and the adjacent water body. This head is equivalent to a tidewater elevation of 100.0 feet M.D.C. (mean low water is elevation 100.8 feet M.D.C.) and a normal fixed pool elevation of 108.0 feet M.D.C. Correspondingly the 8-foot lift could also be experienced when the pool has been prelowered as discussed in Design Memorandum No. 1 to elevation 106.5 feet M.D.C. and the tidewater reaches a high of 114.5 feet M.D.C. (mean high water is elevation 110.2 feet M.D.C.). The latter case, as it depends on an exceptionally high tide coincident with a prelowered basin, is a remote possibility but nonetheless applicable to the selected culvert design.

b. Losses. - Resistance to flow in the culverts has been calculated as culvert velocity head losses. The head losses were tabulated as the summation of losses in two zones. The first zone begins at the culvert intakes in the lock endwall and extends to the first of the series of wall ports which comprise the culvert "manifold". The region between the first and last ports is considered the second zone. Resistance to flow, because of the symmetrical culvert design, is taken as equal (for a given static head) for either filling or emptying the lock chamber.

Zone one velocity head loss coefficients, "K" values were computed for:

	<u>4' x 4'</u>	<u>K</u>	<u>6' x 7'</u>
1) Outer rim	.072		.030
2) Bar rack	.159		.200
3) Entrance	.125		.130
4) Intake bends (2)	.200		.200
5) Entrance region contraction	.200		.060
6) Culvert bend (2)	.800		.800
7) Stop log slots (2)	.060		.060
8) Slide gate	.010		.010
9) Sloped invert section, and Friction in culvert	.010		.260
		-----	-----
	K = 1.526		K = 1.750

Head loss coefficients for zone two, the manifold section, were computed for:

- 1) Friction loss in culvert,
- 2) Eddy losses, and
- 3) Head loss in the outlet pipes. Assuming a linear reduction in velocity from the beginning of the manifold to the end, the friction loss reduces to:

$$h_f = \frac{f L_m \times V_{cul}^2}{3D \quad 2g}$$

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Where h_f = friction head losses

f = friction factor

L_m = Length of manifold

V_{cul} = Average velocity in the culvert

$$D = 4 \times \text{Hydraulic radius} = \frac{2(W \times H)}{(W + H)}$$

W = width of culvert

H = height of culvert

Eddy losses in the manifold were assumed as equal to twice the friction loss. The sum of the friction and eddy losses in the manifold then becomes:

$$h_{man.} = \frac{f}{D} L_m \times \frac{V_{cul}^2}{2g}$$

Head loss in the chamber ports is calculated on the principle of equalization of resistance to flow via alternate routes, i.e., the head loss through the first port must be equal to the sum of the head loss through the length of the manifold to any other port and the loss through that port. From continuity the average velocity through the ports, expressed in terms of culvert velocity through the first port to the velocity through the last port, can be ascertained. Expressed in terms of culvert velocity a "K" factor is found for the ports emptying into the chamber. The total energy loss during a lock filling or emptying is then a function of the summation of the velocity head losses, K, for zones one and two, i.e., $H_{LT} = (K_1 + K_2) \times \frac{V_{cul}^2}{2g}$,

where the H_{LT} is the total head loss from pool of lock chamber and K_1 and K_2 are the head loss factors computed as stated above. Similarly for any available head H , the discharge can be expressed as a function of the velocity by substituting the area of the culvert into the above equation, or $H = KQ^2$ where "K" is a constant for a particular culvert and is equal to $K_1 + K_2$.

For any given culvert and manifold system a Head versus Discharge curve can be plotted, which for the fully open valve position yields the discharge for any instantaneous static head. To determine the discharge, rate of rise in the chamber and lock filling or emptying times for any given culvert, a hydraulic analysis during valve opening is necessary. Determination of the above culvert characteristics was made in accordance with the method outlined in EM 1110-2-1604. First the overtravel "d" for each trial culvert size is calculated using the formula stated in EM 1110-2-1604. The overtravel is a result of the momentum of the decelerating mass of water that is present from the time the filling gate is fully opened until the water surface crests in the chamber. This additional head added to the system is accounted for in the rate of rise and lock filling times.

c. Filling Curves. - Minimum valve opening times, t_v , were arrived at for both the large and small locks after considering rate of rise in the chamber, turbulence in the lower approaches and reasonable mechanical limitations on valve components. For comparative analysis a design lift of 8 feet, for the reasons previously stated, was used for each trial culvert. Culvert characteristics were then tabulated for the two stages of operation: (1) during valve opening and (2) valve fully opened, in the same manner as Table A1 in Appendix A of EM 1110-2-1604. Filling curves were plotted from the tabular data, see Plates Nos. 7-8 and 7-9. The overall filling time "T" is approximated from the formula expressed in EM 1110-2-1604,

$$T = m \left(\frac{H}{2g} \right)^{1/2} . \quad \text{If "m", a constant, is taken at the stated average}$$

value of 840 and the design lift of 8 feet is used for the variable H, the overall filling time would be 296 seconds. Design valve opening times of 30 and 60 seconds were used for the small lock and large lock valves respectively. Knowing the respective lock areas, overall culvert sizes that would satisfy the total filling times worked out to approximately 40 square feet for the large lock and 12 square feet for each small lock culvert. Further hydraulic and structural investigation revealed that the small lock culvert sizes could be increased to approximately 20 square feet each to lessen the filling time and improve the lockage capacity. Whereas it would be desirable to also increase the culvert area in the large lock, specific structural limitations preclude a continuous void appreciably in excess of 40 square feet. The trial culvert sizes were 4' x 4' and 4'6" x 4'6" for the small lock and 6'6" x 5' and 6' x 7' for the large lock. The resulting characteristics for each trial are presented in Table 1.

TABLE 1
TRIAL CULVERT DATA

Trial Culvert Feature	Small Lock		Large Lock	
	4'x4'	4'-6"x4'-6"	6'-6"x5'	6'x7'
Area per Culvert (sq.ft.)	16	20.25	32.5	42
Dischg. Coeff. "C"	.569	.519	.486	.429
Overtravel, "d" (ft)	0.24	0.27	0.25	0.25
Max. dischr., Q max. (cfs)	375	444	620	705
Max. Culvert Velocity V_{cul} (fps)	11.7	11.0	9.6	8.4
Max. Rate of Rise (fpm)	4.50	5.29	3.11	3.51
Valve oper. time t_v (sec)	30	30	60	60
Total Filling Time* T (min)	3.50	3.0	4.9	4.4

Based on lift of 8 feet

*Measured to overtravel peak

The 4' x 4' culvert was selected for the small locks because of its favorable maximum rate of rise, filling time and also modular (4' x 8' panel) construction feature. The culvert size selected for the large lock was the 6' x 7'. In addition to the favorable filling and emptying features, the 6-foot width enables the culvert and the 6' x 8' gallery above to have the same vertical formwork planes. The positioning of the ports, facing each other rather than offset, was a result of analytical studies. EM 1110-2-1604 states that this arrangement is satisfactory for low lift operations.

4. WETWELL PUMPING

a. General. - As described above, the pumping capability has been provided primarily for unwatering the navigation locks and the forebay and discharge chambers of the pump station for maintenance and inspection of purposes. However, the capacity provided is somewhat greater than actually required for this purpose. The additional pumping capacity has been provided at the request of the sponsoring agency (MDC) to allow for lowering the navigation locks during the time the tide is higher than the basin by pumping the lock water to tide. This is the operation procedure followed by the sponsoring agency on the nearby Amelia Earhart Locks with the consideration that salt water intrusion is being minimized. Both the large and the small locks have two integrated emptying arrangements leading to the wetwell.

b. Small Lock Lowering. - Below each small lock chamber floor there is a 3' x 3' culvert at right angles to the main axis of the lock chamber. The culverts transition to a 36-inch diameter butterfly valve which opens to the wetwell chamber, see Plates Nos. 7-6 and 7-10. When the butterfly valve is opened, flow passes through the lock chamber sidewall ports into the main filling and emptying culverts and then into the wetwell culvert through a vertical opening at the point where the transverse culvert passes under the main culverts. This method is adequate to lower the chamber water surface to the equalization level at a rate suitable for locking. For total unwatering, this process can be continued until the level in the lock chamber reaches the elevation of the sidewall ports. The remaining 2.5-foot depth below the elevation of the ports is drained by means of scuppers in the chamber floor directly over, and draining into, the transverse culvert. The wetwell acts as a reservoir for the pumps to work under head in pumping to the tide.

c. Large Lock Lowering is accomplished in much the same manner as the small locks. A 3'-6" x 4'-6" transverse culvert is immediately below small lock No. 2 chamber floor connects the wetwell to the large lock filling and emptying culvert in the southerly wall of the large lock. Both culverts are at the same invert elevation. The

TABLE 2
STONE PROTECTION DATA

<u>Location</u>	<u>Flow Velocity in fpm</u>	<u>Req'd Stone Size in lbs.</u>
1. Upstream of J.F. Expressway Pier	1.9	0.05
2. Upstream of Large Boat Lock	4.0	0.70
3. Downstream between Draw Pier and Pier No. 6 of the Charlestown Bridge	7.3	25.00
4. Downstream between Charlestown Bridge Piers No. 6 through 9	2.8	0.10
5. Downstream of 8' x 10' Sluices	6.3	12.00

As shown on Plates 7-16 and 7-17, a 2-foot thick layer of the stone protection will be dumped on a 1-foot minimum gravel bedding where placement will be on dry areas and on a 3-foot gravel layer where placement will be on submerged areas. This protection will extend 40 feet beyond the concrete structures on both the upstream and downstream sides of all the lock structures, except on the downstream side of the large lock. At this location the stone protection will extend 260 feet beyond the concrete structure and will consist of 50 to 500 pound stones on a 1-foot gravel bedding where placement will be on dry areas and on a 3-foot thick gravel layer where placement will be on areas submerged under water. This exception is necessitated by the relatively high discharge velocities at this location. Beyond the stone protection, the maximum computed flow velocities are less than 3 feet per second. Stone protection will not be provided beyond these limits except at the locations of the existing John Fitzgerald Expressway bridge piers and the Charlestown bridge piers. These bridges are located upstream and downstream of the locks, respectively. At these piers the protection against the eddy current scour will consist of a 2-foot thick layer of 5 to 300 pound dumped stone. This layer will extend 8 feet beyond the perimeters of the pier footings (or pile caps).

13. FENDER PIERS AND TRAINING STRUCTURES - The major portion of these structures will be founded on treated timber piles. However, at those locations where it is not possible to achieve adequate penetration into the bearing stratum to provide sufficient lateral restraint, steel H-piles will be used. The inadequate penetration results from the hard driving conditions in the till stratum which, because of its dense and strong nature, will offer excessive resistance. The steel H-piles will be provided with cast steel pile points and coal tar epoxy coating to withstand hard driving conditions and corrosive action, respectively.

G. LOCK OPERATIONS

14. MECHANICAL OPERATION - The mechanical operation of the sector gates and the culvert and wetwell valves is by an oil hydraulic system. As illustrated on Plate 7-18 the sector gates are closed by a hydraulic cylinder moving a rack that in turn rotates a pinion sector. An arm attached to the pinion is hinged to a strut that is pinned to the gate framework. The axial force imparted to the strut forces the gate leaf to rotate into the closed position. The angle of gate rotation for full closure is 63 degrees and 26 minutes. The gate leafs reach the closed position with approximately 4 inches of travel remaining in the rack. The final movement of the rack compresses springs in the strut which hold the gates closed against an allowance for minor slippage in the hydraulic system. During movement of the gates the springs also serve as a cushion to the mechanical system in the event of obstruction jamming. Opening the gates is the exact reverse of closing them. Hydraulic pressure applied in the opposite direction retracts the rack into the cylinder. Hydraulic cylinders for valve and sector gate operation are designed for 2,000 psi working pressure. The working line pressure is 1,000 psi.

15. BASIS OF DESIGN - The basis of design for the gate operating machinery is to provide a gate operating torque sufficient to overcome the seal friction force (Appendix C) developed at maximum operating conditions. The seal friction force results from a water level of 116 on one side and 106 on the other. For this condition, the torque required at the gate pivot is 346 ft. kips. with an oil pressure of 1,100 psi (hydraulic system relief pressure) in the cylinder, the total torque produced at the gate pivot is 605 ft. kips. assuming no loss for machine efficiency (machinery friction). The force required to overcome gate bearing friction and the dynamic forces resulting from sluicing are quite small in proportion to the force required to overcome seal friction. The forces resulting from reverse head condition are discussed subsequently.

16. REVERSE HEAD OPERATION

a. General. - The problems associated with sector gates designed for reverse head (higher head on the concave side of the gate than on the convex side) have been analyzed and resolved in a manner similar to the design of the nearby Mystic River Locks sector gates. The problem is essentially one of providing side seals capable of water tight closure in either direction; the head reversal occurring with each tide cycle. The differential force across the gate framing resulting from reverse flow through the miter is quite small

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?1

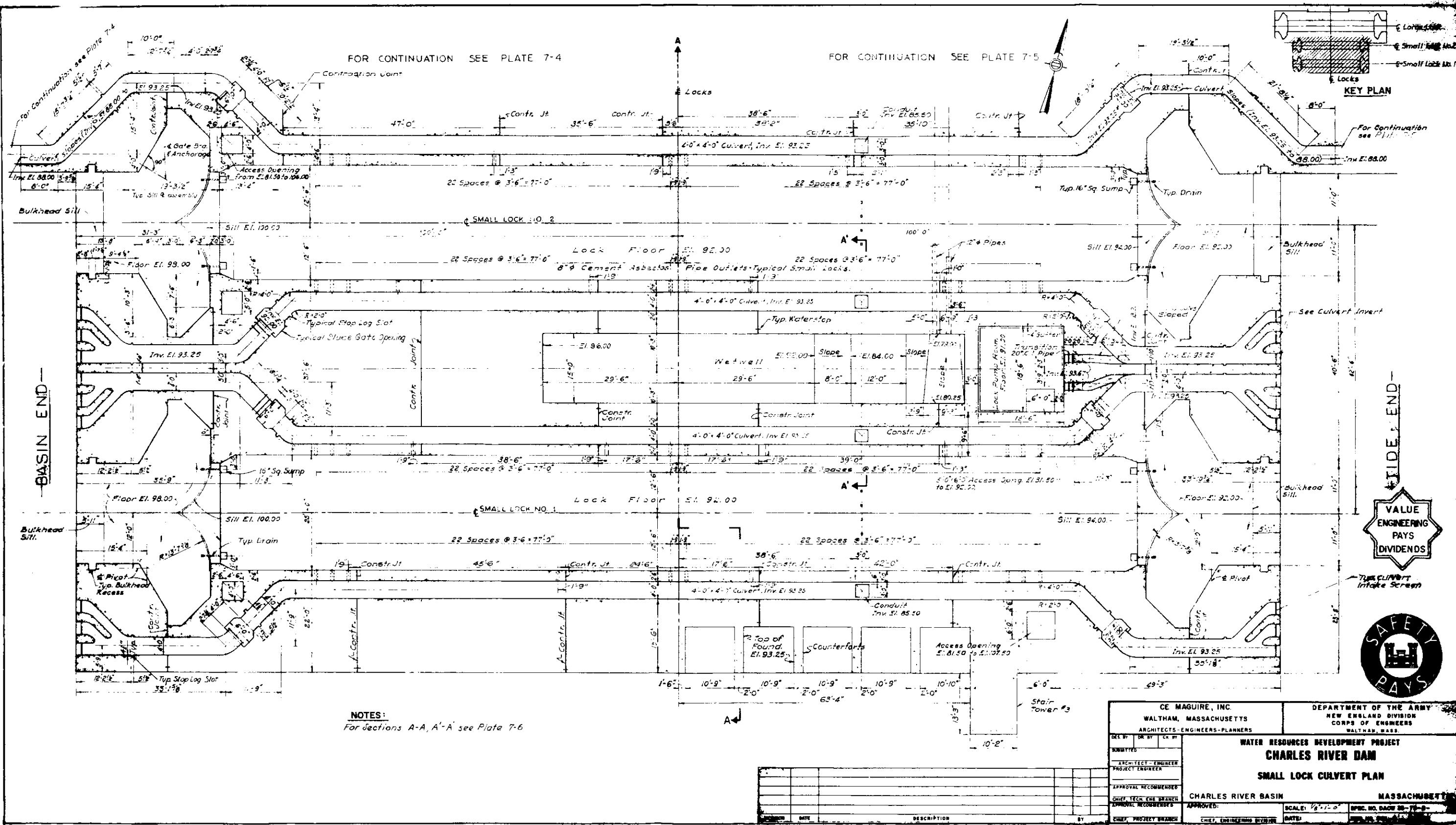
Rev. Aug 73

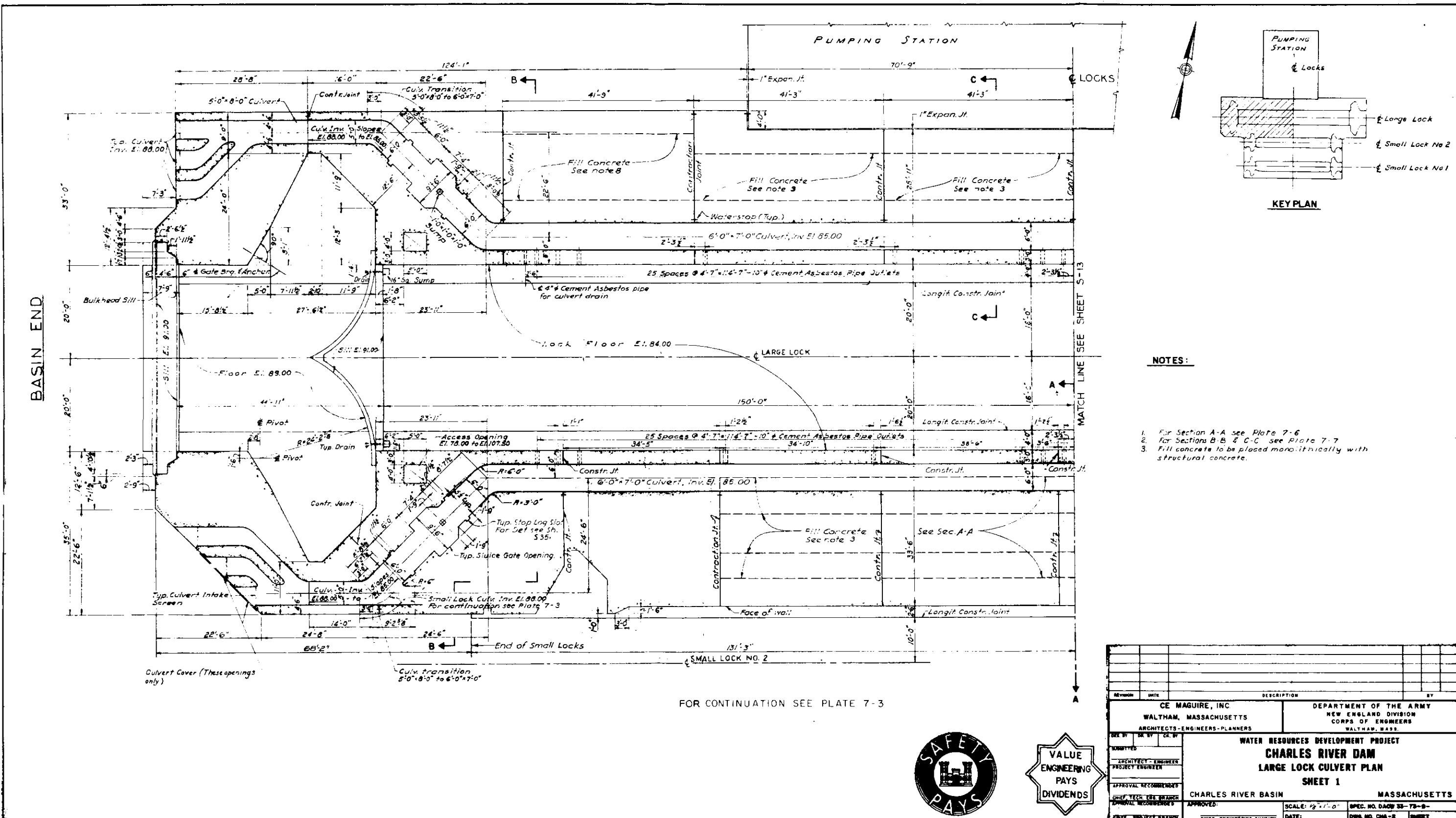
compared to the force available. The greatest force for reverse head for the large lock under the maximum operating condition produces a hydrostatic closing force on the side seal assembly of 2.7 kips. or a torque of 65 ft. kips. at the gate pivot. This is also small compared to the torque capability of the machinery.

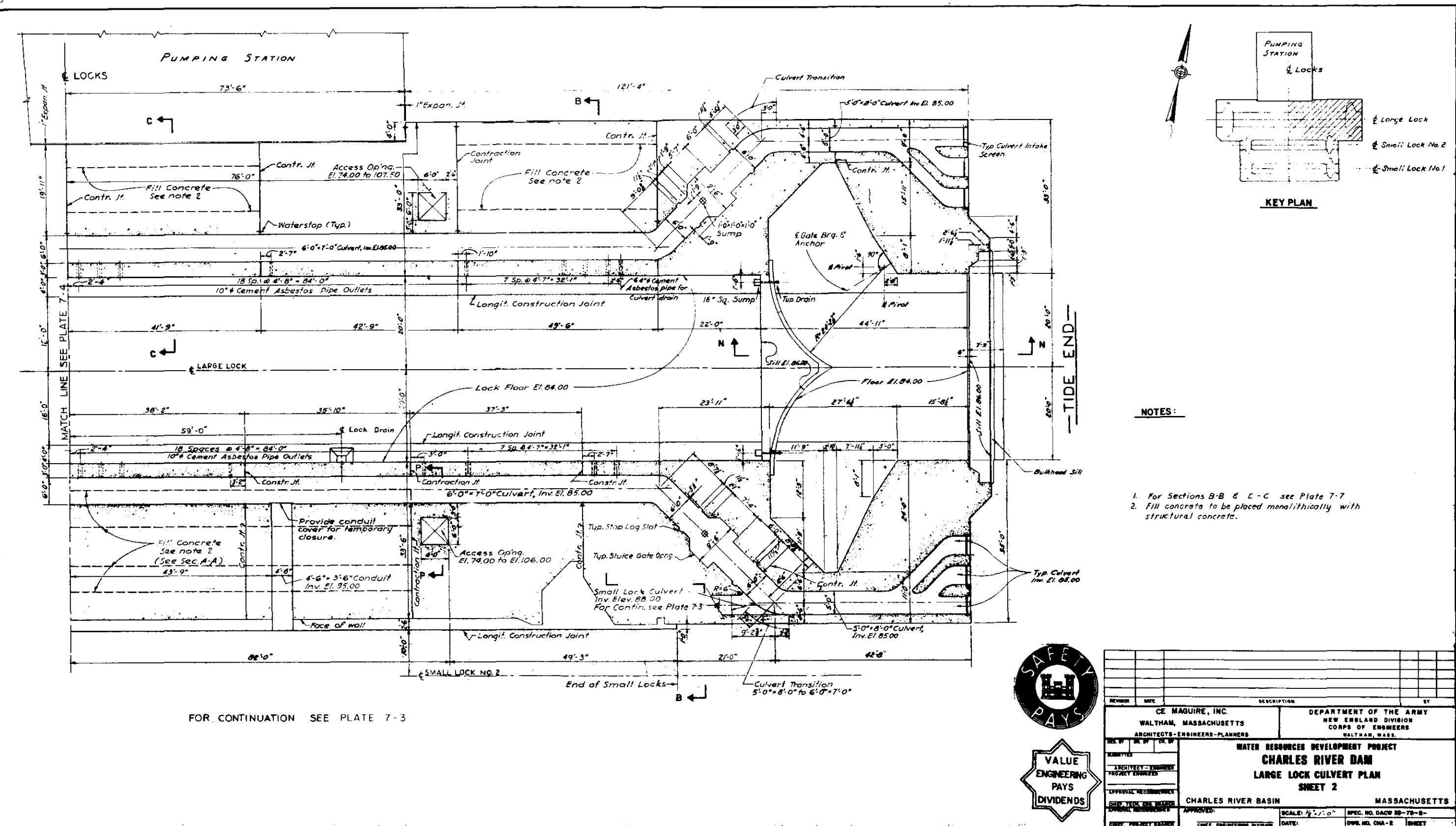
b. Experience of Mystic River Dam. - Similar in design and operating conditions, the existing Mystic River Dam lock gates have successfully operated under reverse head conditions. Both basin and tide end gates (which face in opposite directions) have been used for flood sluicing and there has been no perceptible difference in operation of the gate, either opening or closing.

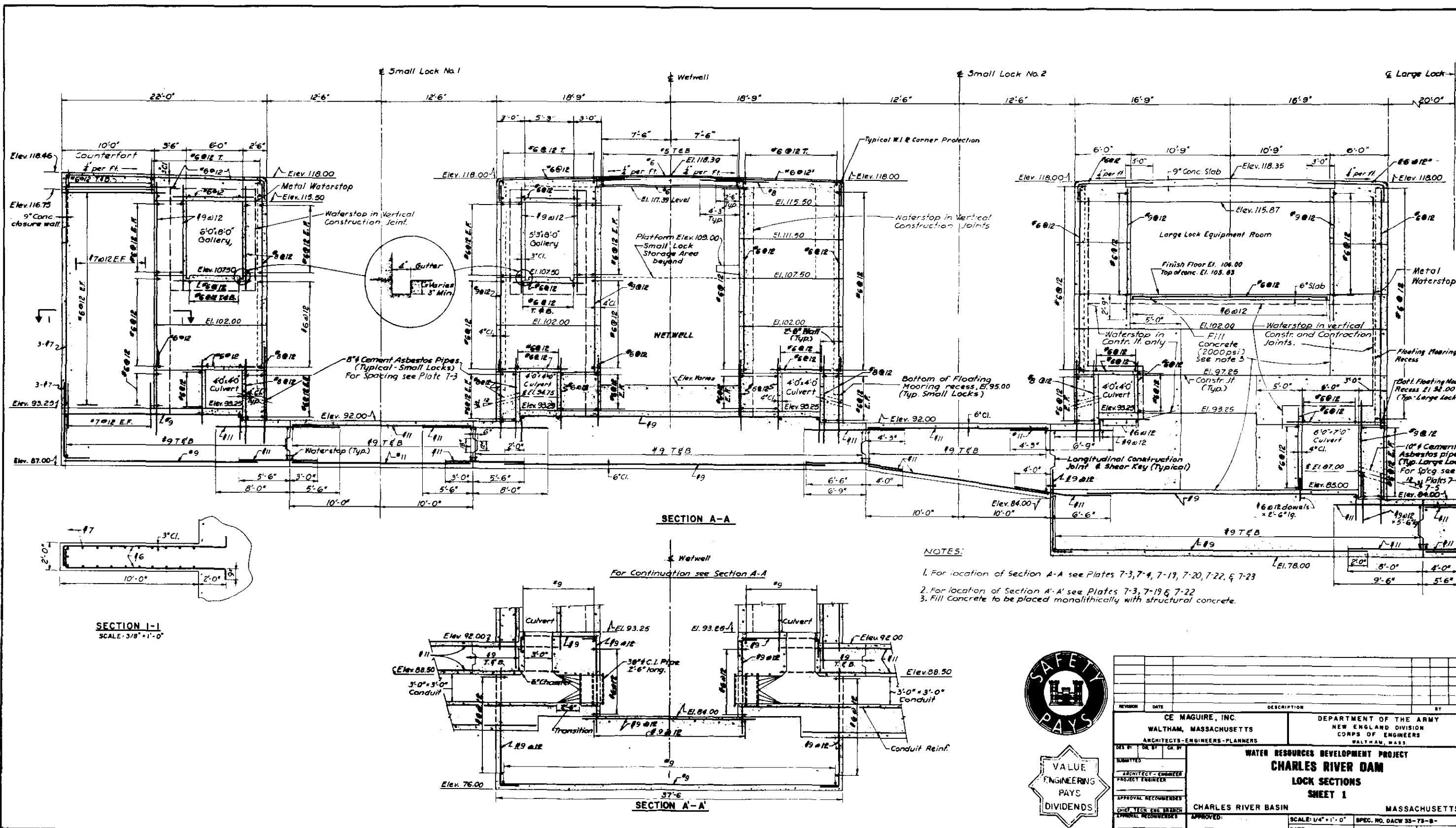
On one occasion, with the large lock dewatered, and with a reverse head of high tide against the tide end gate, an unsuccessful attempt was made to open the gate. Not unexpected the reverse head, approximately 27 feet, was more than twice the design maximum operating head. However, the gate subsequently opened when the reverse head was reduced by lock filling to about 20 feet.

17. LOCK BULKHEAD PLACING AND STORING - The proposed plan for lock bulkhead placement is to barge either the large or small lock bulkhead members from the existing Mystic River Locks and Dam. The bulkhead recesses in the proposed large lock have been designed to accommodate the bulkhead of the wider Mystic River large lock (40 feet vs. 45 feet). No modification in the recesses was required for the small locks as both sites use the same lock width. Actual placement of the bulkhead sections could be done by either a rubber-tired crane operating from the deck area or a crane operating off the barge. EM 1110-2-2602 states that bulkheads should be stored as close as possible to the lock chambers. The additional cost for bulkheads, storage provisions and handling apparatus is not justified since emergency closures can be made at the proposed lock by mechanically closing either of the sector gates.

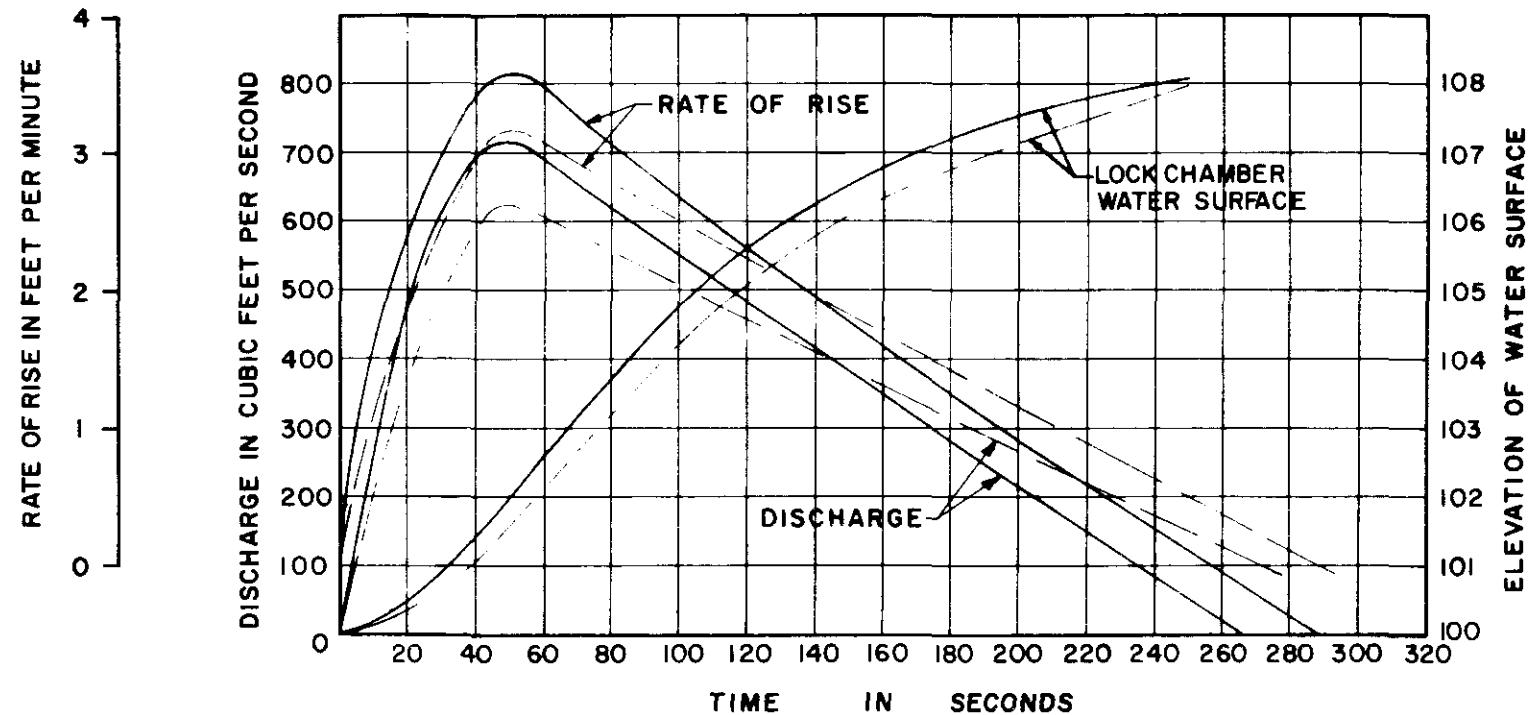
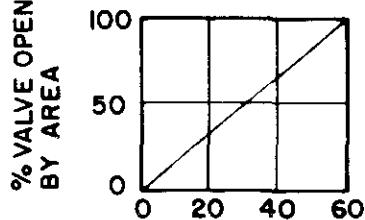








VALVE OPENING TIME



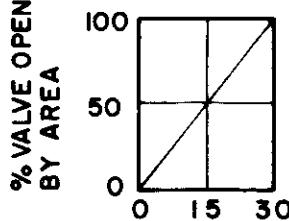
LEGEND

- 7'X6' CULVERT —————
- 6'-6"X5' CULVERT -----

PLATE 7-8

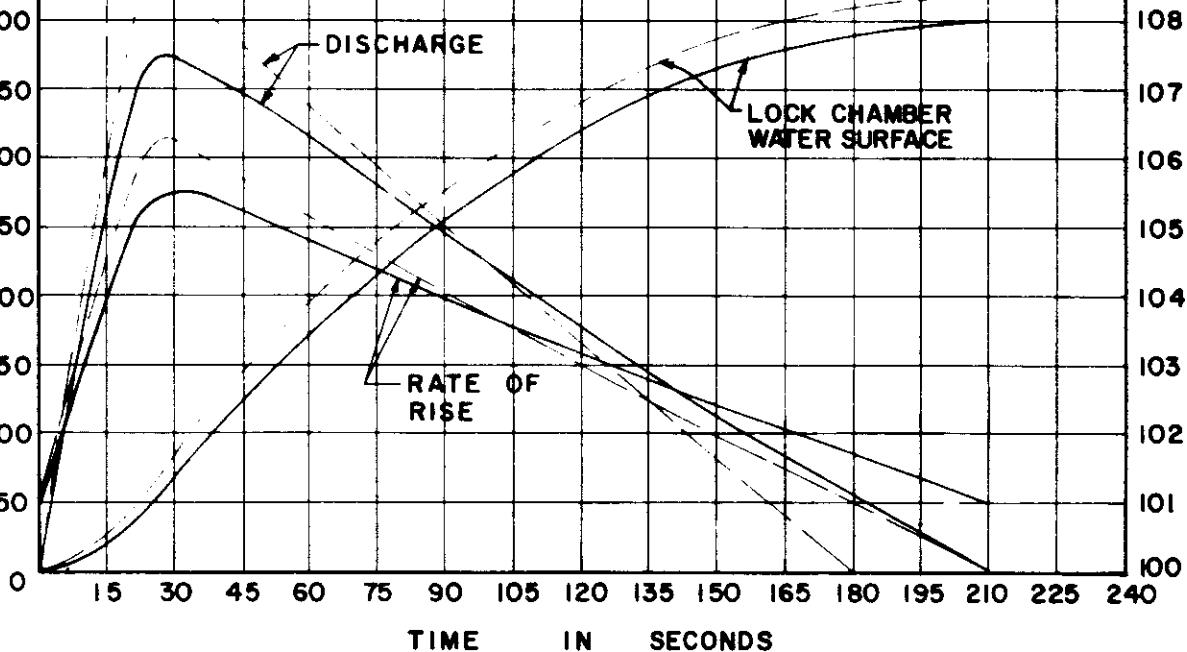
WATER RESOURCES DEVELOPMENT PROJECT
CHARLES RIVER LOCKS AND DAM
 CHARLES RIVER BASIN MASSACHUSETTS
 LARGE LOCK
 FILLING CURVES
 DEPARTMENT OF THE ARMY
 NEW ENGLAND DIVISION
 CORPS OF ENGINEERS WALTHAM, MASS.
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VALVE OPENING TIME



RATE OF RISE IN FEET PER MINUTE
6
5
4
3
2
1
0

DISCHARGE IN CUBIC FEET PER SECOND



TIME IN SECONDS

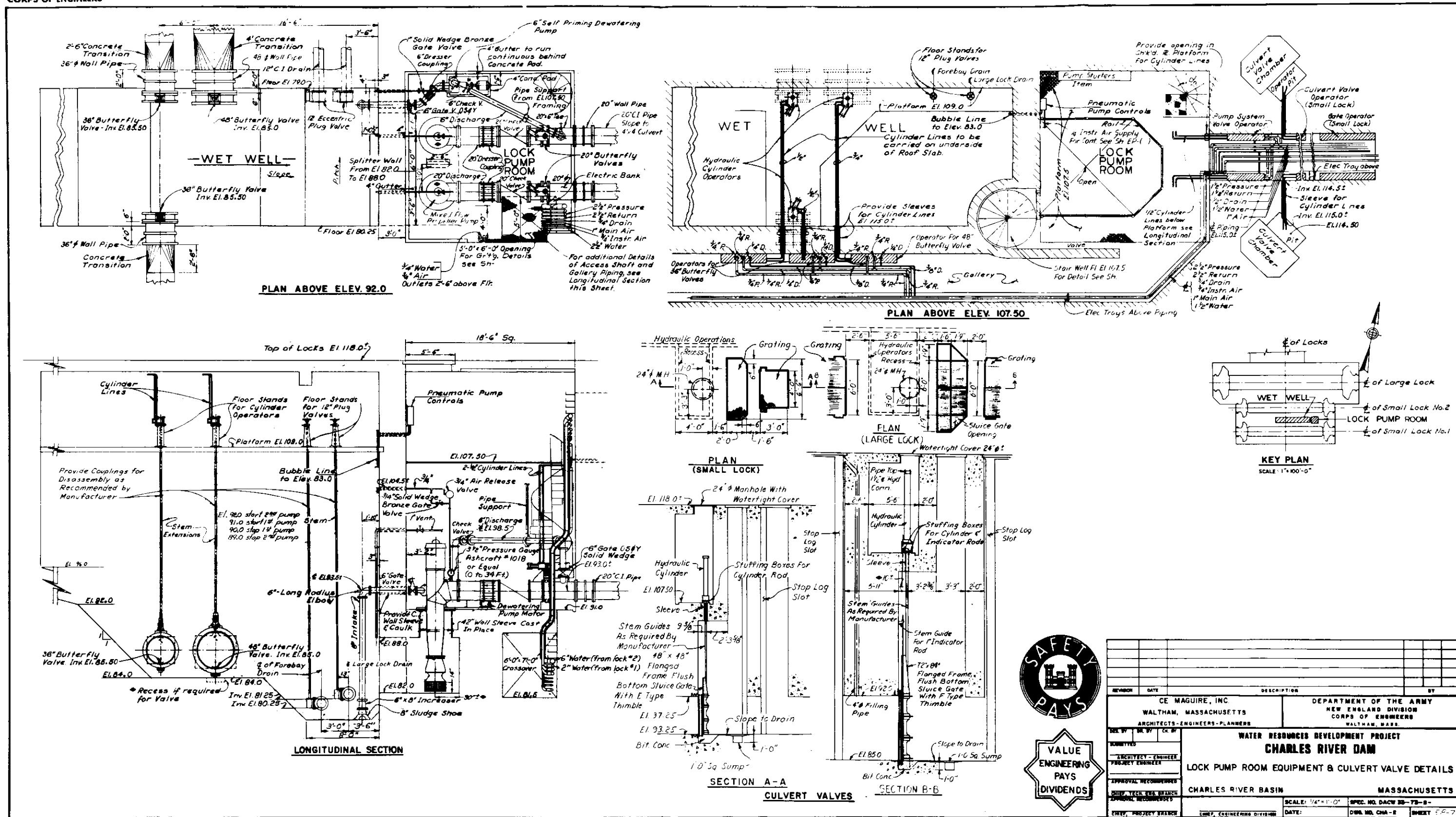
LEGEND

- 4'x4' CULVERT —————
- 4'-6"x4'-6" CULVERT - - - -

PLATE 7-9

WATER RESOURCES DEVELOPMENT PROJECT
CHARLES RIVER LOCKS AND DAM
CHARLES RIVER BASIN MASSACHUSETTS
SMALL LOCK
FILLING CURVES
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS WALTHAM, MASS.

REVISED AUG. 1973

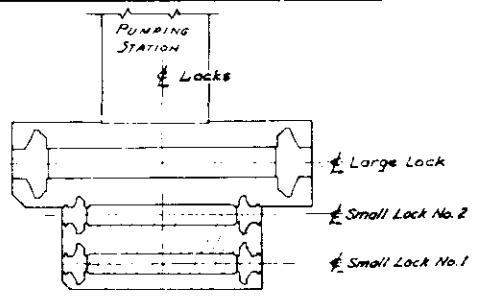


BASIN END

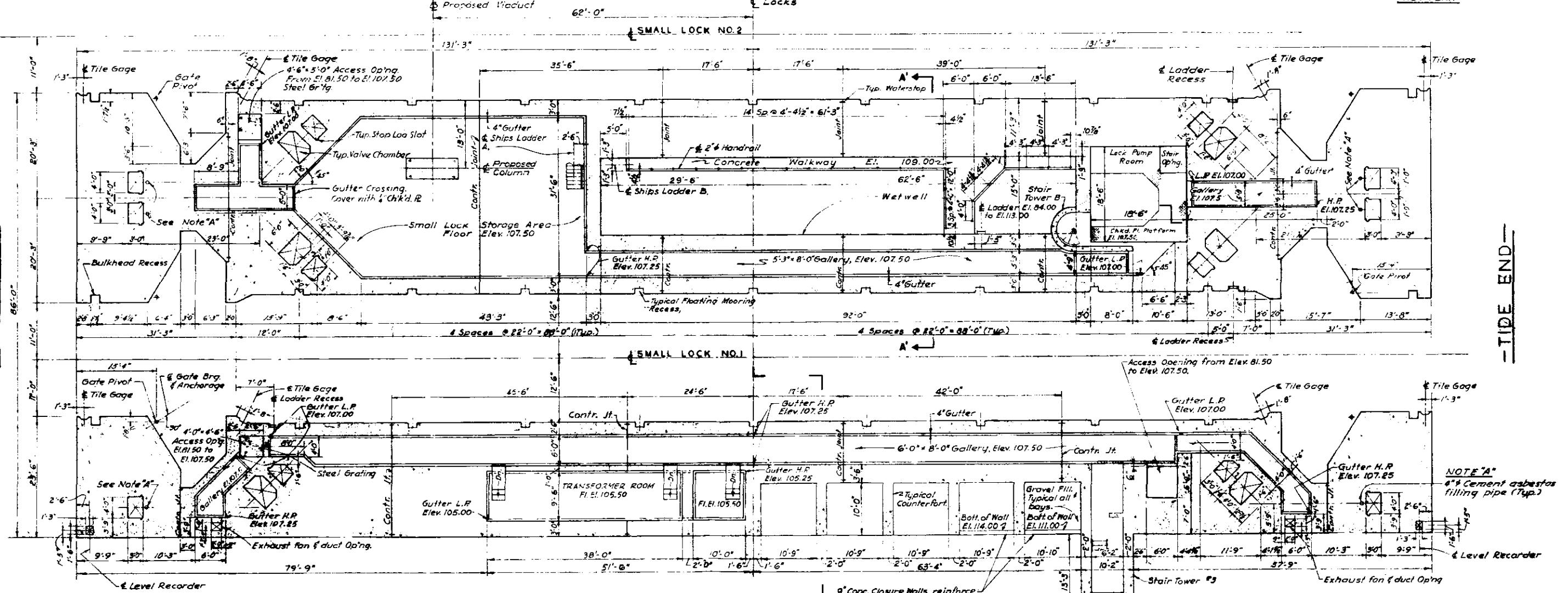
-TIDE END-

FOR CONTINUATION SEE PLATE 7-20

FOR CONTINUATION SEE PLATE 7-21



KEY PLAN



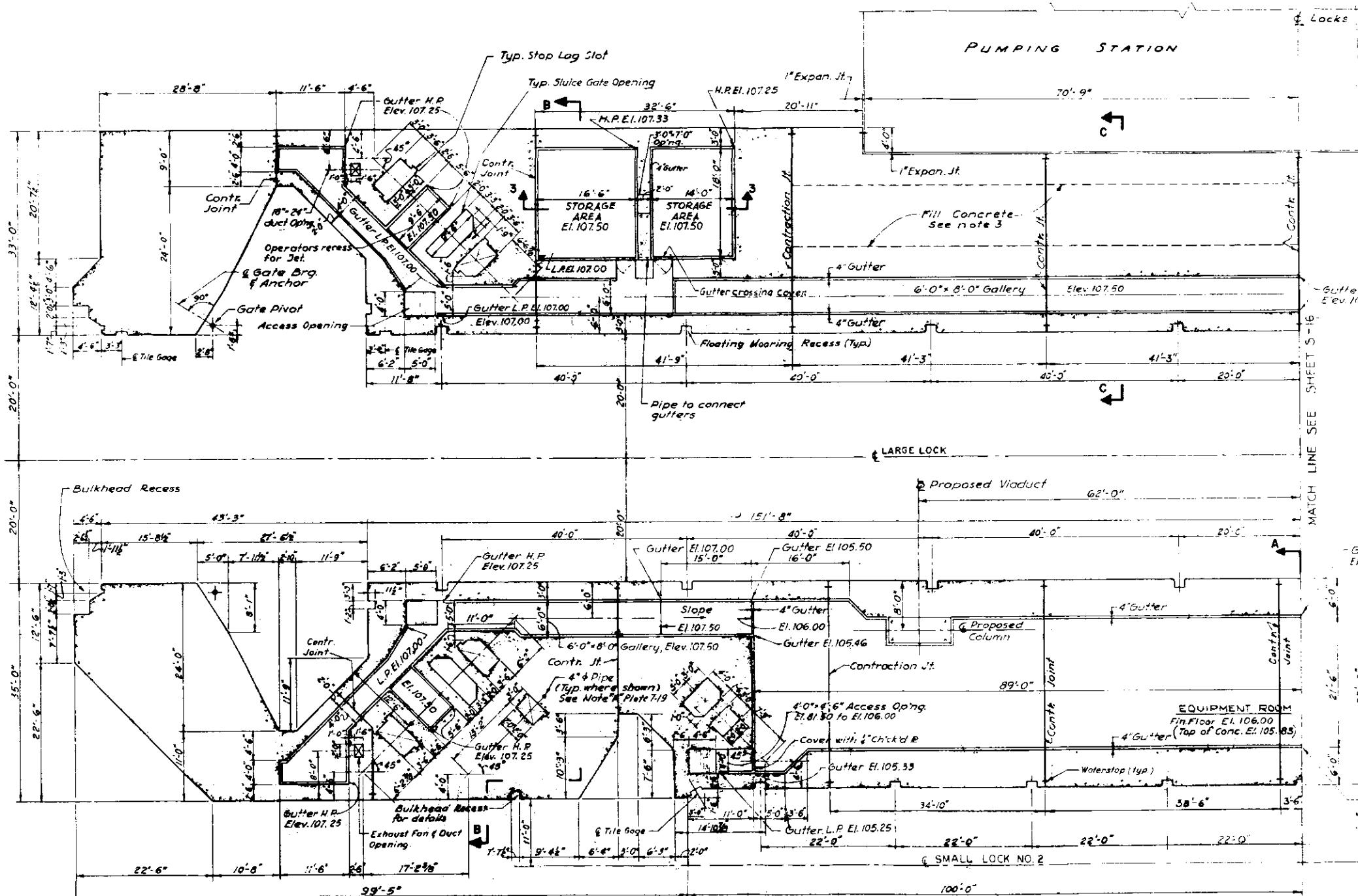
NOTES:
For sections A-A and A'-A' see Plate 7-6.

A ← 9" Conc. Closure Walls, reinforce
with #5 @12 E.W. E.E. tie into
counterforts, stair tower and
underside of slab.



CE MAGUIRE, INC. WALTHAM, MASSACHUSETTS ARCHITECTS-ENGINEERS-PLANNERS			DEPARTMENT OF THE ARMY NEW ENGLAND DIVISION CORPS OF ENGINEERS WALTHAM, MASS.
DES BY	DR. BY	CR. BY	
			WATER RESOURCES DEVELOPMENT PROJECT CHARLES RIVER DAM
			SMALL LOCKS GALLERY PLAN
APPROVAL RECOMMENDED		CHARLES RIVER BASIN MASSACHUSETTS	
SWINNEY & CO., INC. APPROVAL RECOMMENDED		APPROVED:	
		SCALE: 1/2" = 1'-0"	SPEC. NO. DAWC 38-73-B-
		DATE: 10-10-67	DRAW. NO. CHA-7 SHEET

BASIN END



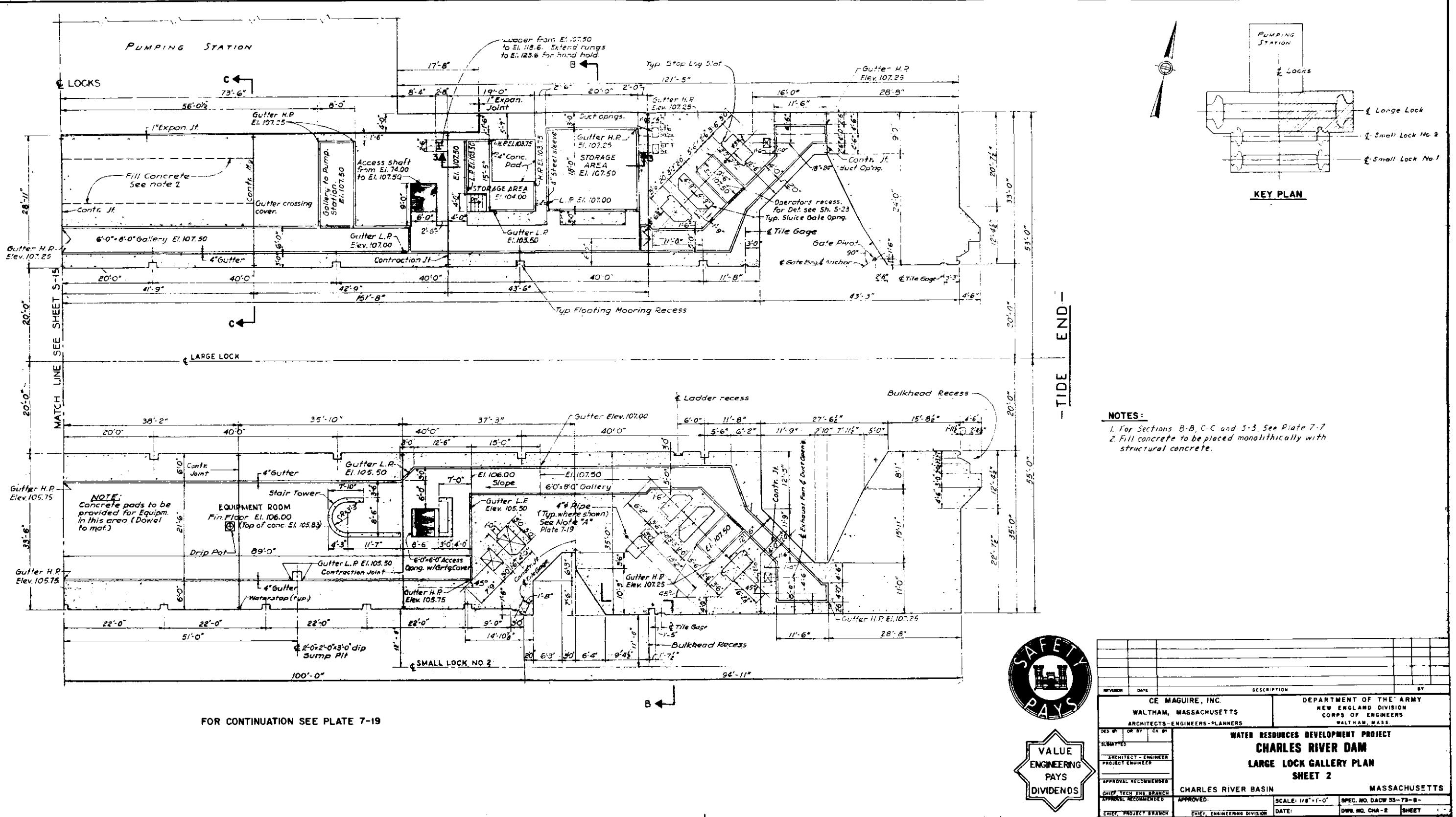
FOR CONTINUATION SEE PLATE 7-19

1 For Section A-A see Plate 7-6
2 For Sections B-B, C-C & 3-3 see Plate 7-7
3 Fill concrete to be placed monolithically with structural concrete.



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WALTHAM, MASSACHUSETTS			NEW ENGLAND DIVISION		
ARCHITECTS-ENGINEERS-PLANNERS			CORPS OF ENGINEERS		
WALTHAM, MASS.			WATER RESOURCES DEVELOPMENT PROJECT		
DES BY	DR BY	CK BY	CHARLES RIVER DAM		
SUBMITTED			LARGE LOCK GALLERY PLAN		
ARCHITECT - ENGINEER			SHEET 1		
PROJECT ENGINEER			CHARLES RIVER BASIN		
APPROVAL RECOMMENDED			MASSACHUSETTS		
CHIEF, TECH ENG BRANCH			APPROVED:	SCALE: 1/8" x 1'-0"	SPEC. NO. DACW 35-73-B-
APPROVAL RECOMMENDED			CHIEF, PROJECT BRANCH	DATE:	DWL. NO. CHA-2 SHEET
CHIEF, ENGINEERING DIVISION					

Kor. 251 Aug 73 PLATE 7-20



FOR CONTINUATION SEE PLATE 7-19

FOR CONTINUATION SEE PLATE 7-23

FOR CONTINUATION SEE PLATE 7-24

KEY PLAN

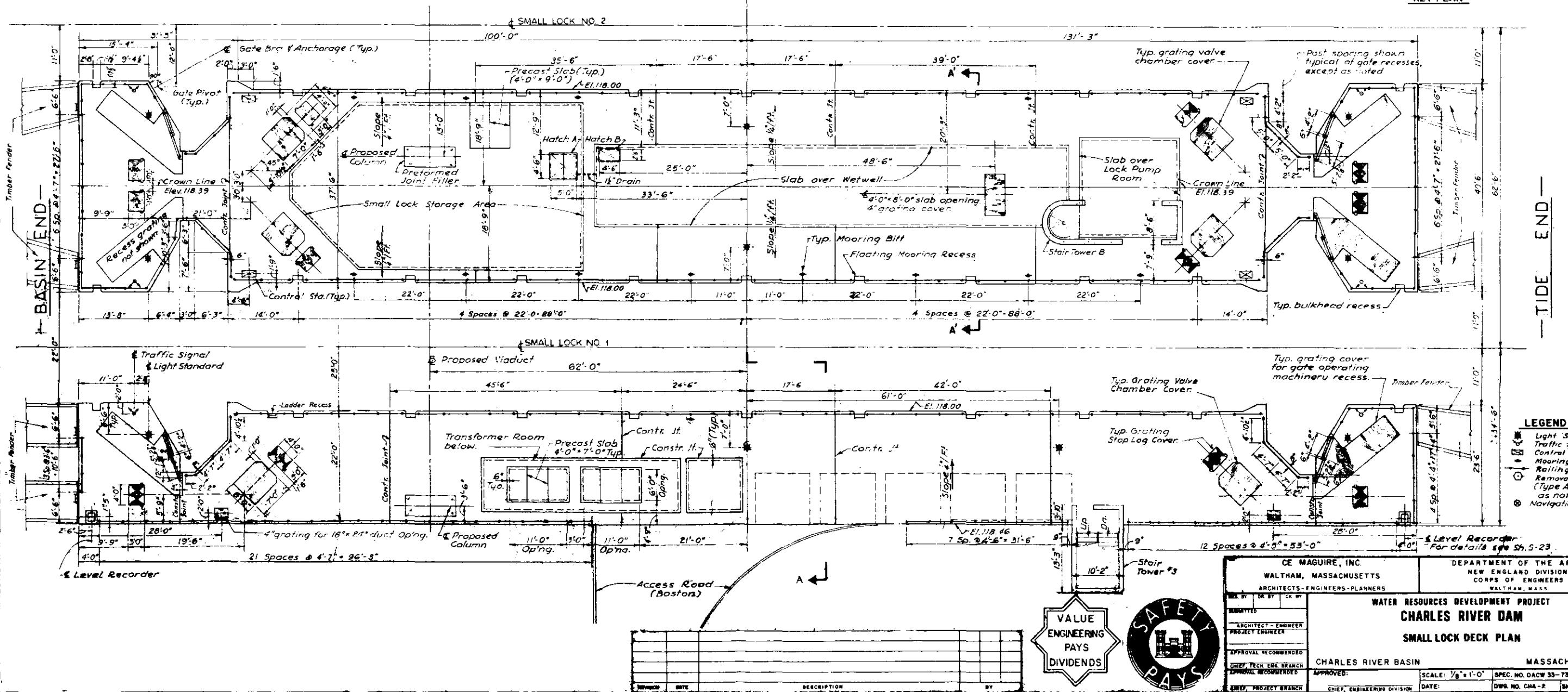
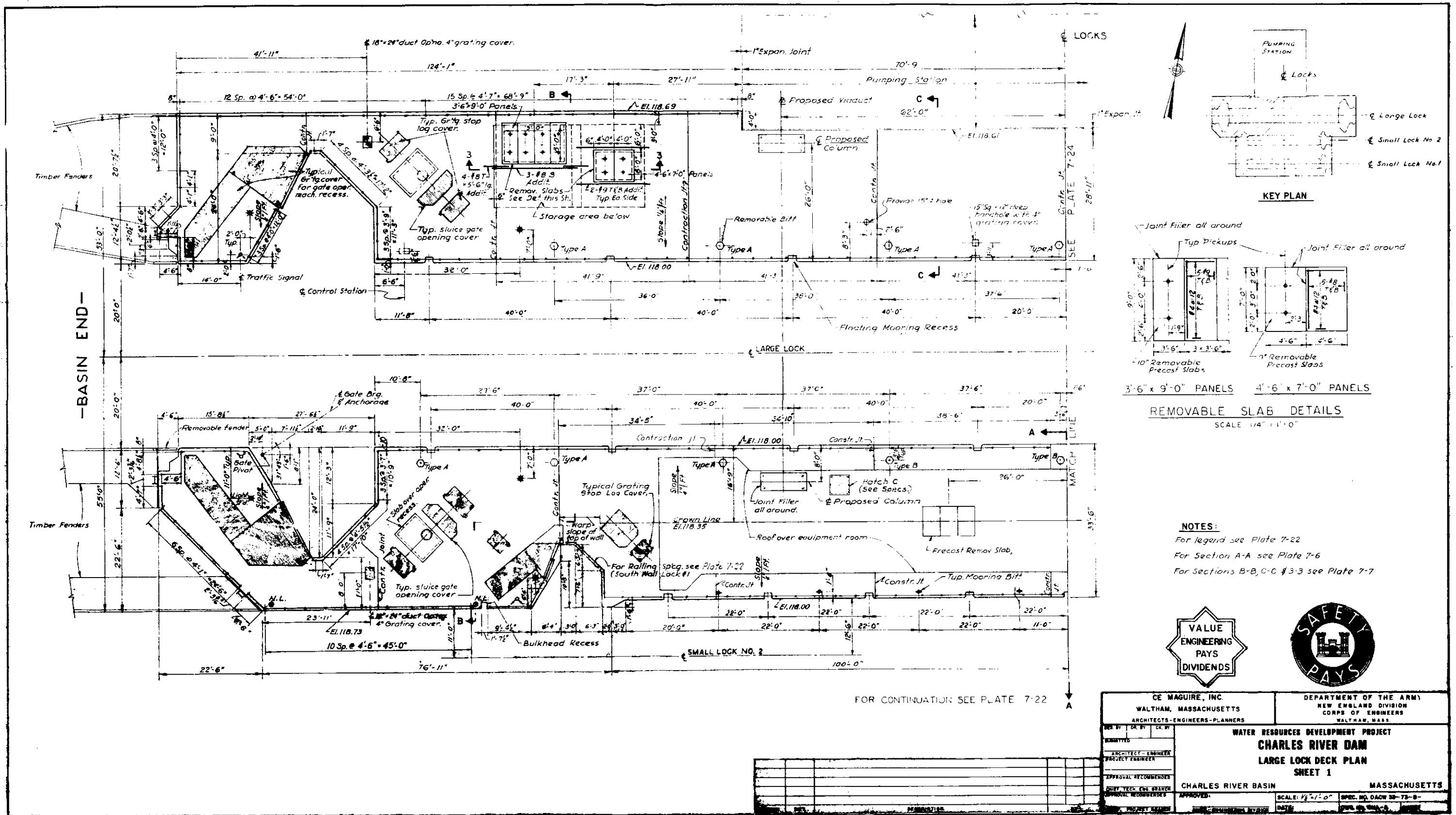
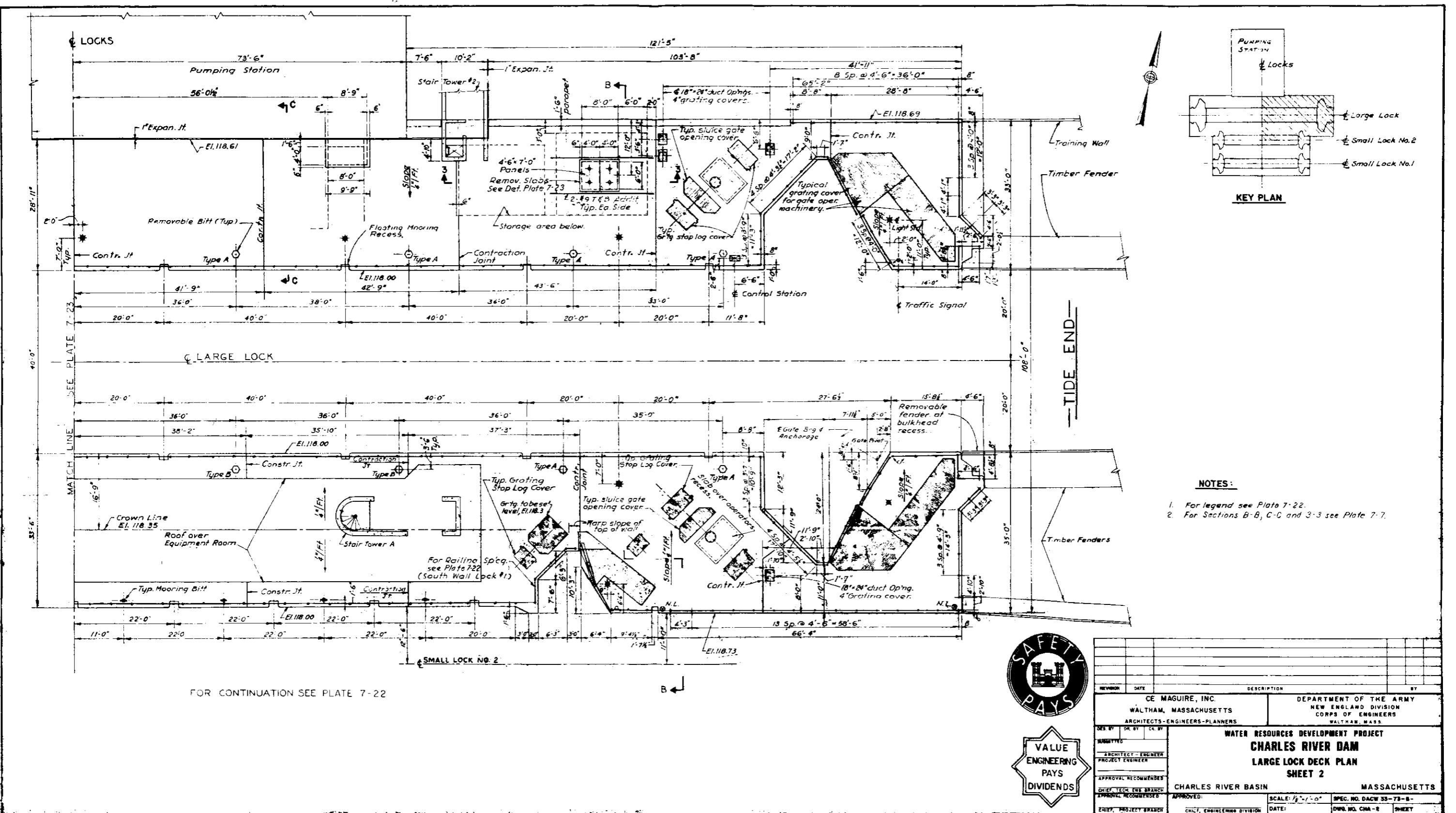


PLATE 7-22





Revised Aug. 73 PLATE 7-24